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Persistence and Variation on the Groundfish Assemblages on Flemish Cap (NAFO Divisions 3M): 2004-2013

by

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Abstract

Data from the EU (Spain-Portugal) bottom trawl surveys in the Division 3M of the NAFO Regulatory Area (2004-2013) were analyzed to examine patterns on this zone of groundfish assemblage structure and diversity in relation to depth. 1699 hauls between 129 and 1460 m in depth were carried out. We focused on the 29 most abundant species, which made up 87.5% of the catch in terms of biomass.

Assemblage structure was strongly correlated with depth. For the most part, changes in assemblages seem to be fairly continuous, although there were more abrupt changes at 600 m. Three main assemblages were identified. A shallow assemblage was found in the shelf. Assemblage I (Shallow) comprises the strata with depths lesser than 250 m and include American plaice (*Hippoglossoides platessoides*), witch flounder (*Glyptocephalus cynoglossus*) and Atlantic cod (*Gadus morhua*). Assemblage II (Intermediate) includes the strata with depths between 251 and 600 m and comprises Acadian redfish (*Sebastes fasciatus*), Arctic eelpout (*Lycodes reticulates*), thorny skate (*Amblyraja radiata*), longfin hake (*Phycis chesteri*), deepwater redfish (*Sebastes mentella*), spinytail skate (*Bathyraja spinicauda*) and Northern

wolffish (*Anarichas denticulatus*). Three species are present in the two first assemblages: Atlantic wolffish (*Anarichas lupus*), golden redfish (*Sebastes marinus*) and spotted wolffish (*Anarichas minor*). Assemblage III (Deep) contains the depth strata greater than 601 m. Marlin-spike (*Nezumia bairdii*), scaly dragonfish (*Stomias boa*), Greenland halibut (*Reinhardtius hippoglossoides*), sloane's viperfish (*Chaulonius sloani*), black dogfish (*Centroscyllium fabricii*), Snubnosed spiny eel (*Notacanthus chemitzii*), roughhead grenadier (*Macrourus berglax*), roundnose grenadier (*Coryphaenoides rupestris*), blue antimora (*Antimora rostrata*), threadfin rockling (*Gaidropsarus ensis*), bean's sawtoothed eel (*Serrivomer beanii*), Northern cutthroat eel (*Syphanobranchus kaupii*), lanternfish (*Lampanyctus sp*), vahls's eelpout (*Lycodes vahlii*), Arctic skate (*Amblyraja hyperborea*) and Demon catshark (*Apristurus sp*) formed Assemblage III. Despite dramatic changes in biomass and abundance of the species in the area, the boundaries and composition of the assemblages seem to be similar to the period before the collapse. Extending depth range to 1460 m, no another boundaries were found. Although some changes were evident, the main ones were replacements of the dominant species in several assemblages and bathymetric range extension of distribution of some species. Acadian redfish and golden redfish appear to be the dominant species in the shallowest assemblage instead of Atlantic cod that were dominant in the period before the collapse in the area; redfish is the dominant species in the second shallow and intermediate assemblages

Diversity appears inversely related to biomass in the different assemblages. Despite the collapse in some species and the permanent fishing activity target to the North Shrimp (*Pandalus borealis*), redfish (*Sebastes spp*) and Greenland halibut, the overall pattern of demersal fish assemblages remains similar over time. This pattern is similar in other Atlantic areas; it indicates that changes in the fish populations in Northwest Atlantic have been produced on a large scale and are not limited to specific areas.

Introduction

Changes in ocean climate combined with direct and indirect effects of harvesting can dramatically and rapidly alter the composition of marine fish communities (Hutchings and Reynolds, 2004). The global crisis in overexploitation of fisheries has resulted in calls for multispecies or "ecosystem-based" assessment and management of fish stocks and assemblages (Jennings and Kaiser, 1998; Pauly *et al.*, 2002; Worm *et al.*, 2009). An ecosystem approach to fisheries management in marine waters has long been advocated to gain a better understanding of the structure and functioning of ecosystems and to eventually restore and sustain them (Tolimieri and Levin, 2006). A first step towards ecosystem management is to reduce the complexity of the ecosystem and search for patterns by describing species abundance and distribution to identify species assemblages and the biological and environmental conditions associated with these assemblages (Mahon and Smith, 1989; Gomes *et al.*, 1992; Tolimieri and Levin, 2006). Implementation of multispecies approaches requires improved understanding of the community ecology of fish assemblages, but this information has rarely been explicitly incorporated into management practices. Although single-species management is still commonly practiced, in recent decades numerous papers have described demersal fish assemblages: in tropical areas (Bianchi, 1991); in the Scotian Shelf and the Gulf of St Lawrence (Bundy, 2005); Norwegian Sea (Lekve *et al.*, 1999); in the Mediterranean Sea (Moranta *et al.*, 1998); in the NW Iberian Peninsula (Fariña *et al.*, 1997); off the East coast of North America (Mahon *et al.*, 1998; Tolimieri and Levin, 2006); off the West coast of North America (Cope and Haltuch, 2012); in the mid-Atlantic (Azores Archipelago - Menezes *et al.*, 2006). Mahon and Smith (1989) identified ten offshore assemblages of relatively similar species composition on the Scotian Shelf and Bay of Fundy, from 1970 to 1981; in the depth range until 730 m in the Flemish Cap (NAFO Div. 3M) three main assemblages were identified (Paz and Casas, 1996; González-Troncoso *et al*., 2006); Villagarcía (1995) studied the structure and distribution of demersal fish assemblages on the Northeast Newfoundland and Labrador Shelf; Gomes *et al.* (1992) found six assemblages over 16 years (1971-82, 1984-87) on the Grand Banks of Newfoundland; Nogueira *et al.* (2013) found five assemblages in the South of the Grand Banks (Regulatory Area of NAFO Div. 3NO).

Rose (2003) provides an overview of the fisheries resources and science in Newfoundland and Labrador. The Flemish Cap Bank (NAFO Div. 3M), part of the Labrador Newfoundland Large Marine Ecosystem (Figure 1), are an internationally known fishing ground most noted for cod, but haddock, redfish, flatfish (including halibut), mackerel and herring are also caught. Due to its geographical isolation fishing started late. The Flemish Cap is an isolate bank located in NAFO Division 3M and centred at about 47ºN 45ºW (Figure 1). It is separated from Newfoundland by the Flemish Pass, a channel with depths greater than 1100 m and located at more than 300 nautical miles from Newfoundland. Templeman (1976) provides a background of the biology and hydrography of the Flemish Cap area. Stein's (1996) presented an overview of the oceanography of the zone.

The Flemish Cap is completely within international waters. In 1977, with the establishment of Canada's 200 mile limit and declaration of its Exclusive Economic Zone (EEZ), fishing effort in this bank was extremely intensified by the international fishing fleet.

In 1998, the collapse of cod stocks led to the imposition of a moratorium on fishing cod over the Flemish Cap. This stock has been under moratorium since 1999 to 2009. The collapse has been attributed to three simultaneous circumstances: a stock decline due to overfishing, an increase in catchability at low abundance levels and a series of very poor recruitments starting in 1993 (González-Troncoso *et al.*, 2013). The collapse of main commercial species also occurs in the Grand Banks of Newfoundland in 1991-92 and coincided with unusual ice conditions and a broadening of the cold intermediate layer of the Labrador Current. This coincidence fuelled speculation that cold water had killed or driven out the cod (Young and Rose, 1993). In some quarters, the speculation was hopeful: perhaps nature, and not overfishing, was to blame for this ecological disaster. But on finer scales, the cold water distribution appeared patchy, and even at its greatest extent, there remained vast areas still suitable for cod (Haedrich and Barnes, 1997). Careful analysis reached the conclusion that overfishing alone best explains the Northern cod collapse (Hutchings and Myers, 1995; Sinclair and Murawski, 1997). Cold water could have facilitated

overfishing, however, by concentrating the cod and making them easier to catch (Martin, 1995). After the collapse, fishing on the Flemish Cap has mainly focused on an increasing population of North Shrimp and Greenland halibut (Anon., 2002; Casas-Sánchez, 2010; Pérez-Rodríguez, 2012). Due to the decrease of Northern shrimp last years, current fisheries are targeting cod at depths less than 300 m, redfish in depths less than 700 m and Greenland halibut in depths more than 700 m.

With the extension of deep-sea fisheries, there has been increased interest in the ecology of deep-sea species (Priede *et al.*, 2010). Previous studies have examined the fish assemblages on the Flemish Cap. These studies, however, covered limited depths (Paz and Casas, 1996; González-Troncoso *et al.*, 2006).

The EU (Spain and Portugal) has performed a bottom trawl survey on Flemish Cap since 1988 (NAFO Regulatory Area Division 3M) (Figure 1). After ten years of cod moratorium, some symptoms of return to the situation "pre-collapse", as relative increase of cod biomass and significant decline of Northern shrimp biomass (Casas-Sanchez, 2010), can be seen. We will try to test changes in assemblages of Flemish Cap and update previous results of Paz and Casas (1996) and González-Troncoso *et al.* (2006). In this study we use data from this survey to examine biomass distribution, to describe the assemblage structure of the dominant fish fauna in the Flemish Cap during the period 2004-2013 and to explore the possible changes that have taken place in the communities over this period, including species composition and interaction as well as depth distribution and diversity. Specifically, this study was intended to identify, describe and map broad groundfish assemblage areas over a wide depth range (129-1460 m), further expanding on previous works in the area. Specifically, we (i) extend the bathymetric range for the identification and description of fish assemblages; (ii) determine whether the species assemblages of demersal fish follow similar depth patterns in temporal scale in the area; and (iii) ask whether there were any changes in the dominant species in each assemblage.

Material and Methods

Material

We used data from the EU bottom trawl survey to estimate abundance and biomass of demersal resources in the Div. 3M of the NAFO Regulatory Area. This survey has been carried out every year since 1988 in summer (June-July). From 1988 to 2003, it was conducted on board the R/V *Cornide de Saavedra* and, since 2004, the R/V *Vizconde de Eza* has replaced the former vessel in conducting surveys using a *Lofoten* type bottom trawl. In 2003 and 2004, comparative surveys between the two vessels were made in order to transform the historic time series into the new vessel index. The survey indices of the most important species were transformed to use the whole time series in the assessments of these species. For details of the indices transformation, see González-Troncoso and Casas, 2005. In our study species that are not usually assessed have been used, although the transformation of their indices is not available. For this reason we used data from 2004 to 2013. Hauls were made following the stratification charts described in Bishop (1994). Sets were allocated in accordance with the area of the strata, with a minimum of two planned hauls per stratum. Trawl positions were chosen randomly. Abundance and biomass for all species were estimated by the swept area method (Cochram, 1997). The sampling unit consisted in 30-minute hauls at a speed of 3.0 knots using a *Lofoten* otter trawl gear. The mesh size was 35 mm for the net. The mean horizontal opening was 14 m and the vertical opening was 3.5 m. The otter trawl was monitored using a Scanmar net control system. Around 180 valid hauls are made each year. In each haul all the individuals caught are systematically sorted by species and the length distribution is obtained. The mean of the initial and final depth has been used to define the bottom depth of each haul. The mean depth varies from 129 to 1460 m. A total of 1699 hauls were made in the survey between 2004 and 2013 (Table 1).

We included the 29 most abundant species in the survey in our analyses: 26 demersal and three mesopelagic species (Table 2). They consisted on commercial and non-commercial species, but they were potentially dominant species in a given region or potential forage for other species. These 29 species

amounted to 87.5 % of the total catch of the survey. All species were present at least in 7.59 % of the total observed tows.

Methods

The surveyed area, outside EEZs, covering almost the entire bank of Flemish Cap, considered an isolated ecosystem of the continental shelf. The bank has a diameter at the 500 m isobath of about 200 km and a total area of approximately 3.0×10^4 km^2. To the West, the Flemish Pass with water depths of about 1 100 m, separates the Flemish Cap from the Grand Banks of Newfoundland. Bottom trawls are both species and size selective, and it was impossible to adjust this type of selectivity without knowing the behaviour of most species or the real age/size structure of populations.

Before determining groundfish assemblages, some exploratory analysis were conducted to examine if zonation existed, how species were distributed by depth and where depth boundaries existed. The chi-square test, as described by Gardiner and Haedrich (1978), was used for a preliminary investigation of zonation. An analysis of box-plots was performed in order to have an initial descriptive statistical analysis of catch species by depth. To describe semi-quantitative trends in biomass with depth, we constructed graphs of the cumulative distribution of the catches and compared with the empirical cumulative distribution of the depths of the hauls. Finally, in order to quantify zonation, the potential boundaries of depth were examined by calculating the percentage similarity (PS) between the regions involved. Then multivariate analyses were conducted to identify species assemblages. We used cluster analysis to confirm the boundaries found in the PS analysis. Two other multivariate analyses were used in order to confirm the cluster analysis results and to determine which species make up each assemblage: Correspondence Analysis (CA) and Principal Component Analysis (PCA). To investigate the structure within each community and possible changes, we calculated the index of diversity, the total biomass and the CPUE, and the percentage of the total biomass and occurrence for dominant species found in each group resulting from these analyses. Since most of these species co-occur in several assemblages, we

explored size depth trend or bigger-deeper phenomenon of some species. Regression on individual species was performed to establish whether a correlation between size and depth of occurrence existed.

The chi-square test (Gardiner and Haedrich, 1978) was applied to the presence or absence of the species. Bottom trawl hauls available were arranged in order of increasing depth, and the area studied was arbitrarily divided into 10 depth regions of 150 m depth ranges (≤150 m, 151-300 m, 301-450 m, 451-600 m, 601-750 m, 751-900 m, 901-1050 m, 1051-1200 m, 1200-1350 m, ≥1351 m). The number of species that appeared for the first time in each region (upslope boundaries) was recorded. This method tests the distribution across the area of upslope boundaries using the formula:

$$\chi^2 = \frac{Q}{K}\left(V - \frac{K^2}{Q} \right) \qquad \text{with } Q\text{-}1 \text{ degrees of freedom}$$

where: Q = numbers of regions into which the area was randomly divided
K = total number of species
V = sum of squares over all regions of the number of upslope boundaries

The null hypothesis is that the locations of upslope boundaries are uniformly distributed along with the gradient and that there is no tendency towards clustering.

An analysis with box-plot graphs was performed in order to determine the percentiles of the catches by depth. In the box-plot graphs, catches were represented as a function of depth by haul. For identifying associations between catches of the representative species and habitat variable (bottom depth), we characterized the general frequency distribution of depth by constructing its empirical cumulative distribution function (cdf). Commonly, the probability associated with each observation in a cdf is 1/*n*, but the stratified random survey design results in a probability of $1/n_h$ within each stratum h. However, the stratification can be ignored when the allocation of sets is strictly proportional to stratum size (Perry and Smith, 1994). If there were no clear association between fish distribution and depth within the area

surveyed, then the cumulative distribution function for each species would be almost identical to the function for depth. Conversely, when the fish were associated with a small depth range, these functions would be very different.

In order to quantify the zonation, the potential boundaries suggested by the patterns in the cumulative curves were examined by calculating PS between the regions involved. PS is a commonly-used measure of faunal overlap and was calculated following the formula of Whittaker and Fairbanks (1958):

$$PS=100\left(1.0-0.5\sum\left|P_{ia}-P_{ib}\right|\right)$$

where P_{ia} = the proportion observed by species i in sample a
P_{ib} = the proportion observed by species i in sample b

It is known that PS is not sensitive to sample size, but highly sensitive to the relative number of species among the regions involved. So, for example, if the sample size varies excessively among strata and the species number is closely related to sample size, it will lead to a downwardly biased perception of affinities among strata (Koslow, 1993).

We conducted cluster analysis to identify species assemblages and to confirm the boundaries found in the PS analysis. One of the more common types of cluster analysis, tree clustering, was employed. This method uses the dissimilarities or distance between objects when forming the clusters, in which samples were arranged into groups with a similar biotic composition (Clifford and Stephenson, 1975). As the number of hauls (1699) would make interpretation difficult, we grouped into a 100 m depth bin for every two years. These class depths or strata were labelled with the maximum depth value of the class. Therefore, for every two years (2004-2005, 2006-2007, 2008-2009, 2010-2011, 2012-2013) there were 15 strata named: 150, 250, 350,…, 1350, 1500, resulting in a total of 70 strata. The mean number of specimens per strata for each species was root-root transformed ($x^{1/4}$) to dampen the influence of

abundant species (Field *et al.*, 1982). We use Bray-Curtis similarity, which ignores joint absences that are common in marine survey data where many of the species are absent from the majority of the samples (Field and McFarlane, 1968). Moreover, with the root-root transformation and the Bray-Curtis measure, the similarity coefficient is invariant to a scale change (Stephenson and Burges, 1980). The dissimilarity matrix of the data was calculated in R and cluster analysis was carried out with the Statistica program.

To confirm the results of the cluster analysis and to describe which species make up each assemblage, two more multivariate techniques were used, Correspondence Analysis (CA) and Principal Component Analysis (PCA). There are other ordination methods that were developed specifically for ecological data (Ter Braak, 1986; Zuur *et al.*, 2007) and have been used successfully in other studies of demersal fishes (e.g. Bianchi and Hoisater, 1992), but we chose these ones to facilitate the comparison with previous works in near areas (Mahon, 1998; Lorenzo, 2011). CA is an ordination method in which each site is located at the centre of gravity of the species that occur there. This method is unaffected by double-zero, i.e., tows in which both species that are being compared are absent (Kendrick and Francis, 2002). We used PCA to verify the results of the CA with the results of another ordination method. Species loadings on the principal components (PCs) were used to identify groups of species that tend to co-occur (i.e., assemblages). Previous analyses have shown that ubiquitous species may be a member of more than one assemblage, and PCA allows a species to be associated with more than one component. The PCs with eigenvalues >1 are considered to represent statistically significant assemblages (Jolliffe 1986). VARIMAX rotation was used for the PCs having eigenvalues >1 in the unrotated PC extraction (Jolliffe, 1986). Every assemblage can potentially be present at every site, as the assemblages are not mutually exclusive in space. The data and the transformations used in these analyses were the same as those used in the cluster analysis and were performed by Statistica program.

To examine changes in the structure and composition of the groundfish species assemblage, for each assemblage described, the index of diversity (Shannon and Weaver, 1963), the total biomass and the

CPUE, and the percentage of the total biomass and occurrence for the dominant species found were calculated. The Shannon-Wiener index is sensitive both to the number of species and to their relative abundance. A high value of diversity will occur with a high number of equally abundant species, a low value with a low number of species and a species composition dominated by one or a few species.

The "bigger-deeper" phenomenon, in general, refers to the distinct trends in body size over environmental gradients. As a general rule, there is a positive relationship between size and depth**.** Intra-specific bigger–deeper trends have been identified in Collins *et al.* (2005) and in previous works (e.g. Macpherson and Duarte, 1991). To analyze the bathymetric trends of demersal fishes, regressions on individual species were performed. Size was estimated from the mean weight of the species at each set.

Results

A total of 760516.28 kg was caught during the 10-years time series (2004-2013), of which 627212.47 kg were fishes, representing 155 fish species. The 29 species selected made up 87.5% of the total catch (Table 2). Species were caught in depths between 129 to 1460 m. The highest catch corresponded to Acadian redfish. The most present species (% occurrence) were Greenland halibut and marlin-spike (71.57 %). Over the last few years of the studied period, the estimated indices for witch flounder, Acadian redfish and golden redfish increased. Atlantic cod increased and has recovered historical levels since 2009. In 2013, American plaice continued to be below historical levels (Figure 2).

Fish species were not randomly distributed across depths ($x^2 = 74.79$, df = 9, $p < 0.01$), and showed three different patterns of distribution in relation to depth (Figure 3). Two main groups can be appreciate: shallow species with a median depth less than 600 m and deep species with a median depth higher than 601 m. On the other hand, some species presented a limited shallow distribution (e.g., American plaice, Atlantic cod). Other species presented wider bathymetric distribution (e.g., spinytail skate, Northern wolffish). The rest of the species were restricted to a deep range distribution (e.g., black dogfish,

roundnose grenadier). Median depth was less than 250 m for three species, between 251 and 600 m for ten species, and deeper than 601 for sixteen species.

Second analysis was made via empirical cumulative distribution functions of the catches versus the empirical cumulative distribution of the depths of the hauls. It was observed that species presented different behaviour with respect to depth. Species appeared divided into three main groups. Some species presented a distribution above the function for depth; those species have cumulative occurrence percentages higher than 80% in depths less than 400 m. Cumulative distribution of those species was plotted in Figure 4, group A (Shallow). Other species showed no particular association between fish distribution and depth within the area surveyed. This group comprised species with very different behaviour and variability in a wide range of depth (Figure 4, group B (Intermediate)). Other species presented a distribution below the function for depth, with a cumulative occurrence percentage higher than 80% in depths greater than 601 m (Figure 4, group C (Deep)).

The potential boundaries appear to be at 250 m and 600 m. These potential boundaries were examined by calculating the percentage similarities between regions involved. Less value of PS was given at 600 m (3.88 %). This suggests high zonation at this boundary. PS at 250 m was 59.4 %, where zonation is weak.

A cluster analysis was performed to contrast these results. The examination of the dendogram revealed the existence of two main groups associated with the continental shelf and the slope, and three main clusters (Figure 5). Cluster I (Shallow or “Continental Shelf”) comprised the strata with depths lesser than 250 m; cluster II (Intermediate or “Upper Continental Slope”) contained the depth strata between 251 and 600 m and Cluster III (Deep or “Medium-Lower Slope”) the depths greater than 601 m. In agreement with the PS, the dendogram indicated the main boundary at 600 m.

Correspondence Analysis (Figure 6) showed two main groups that can be split in three different groups in agreement with the three clusters of the dendogram. In the Principal Components Analysis (Figure 7), the first three principal components accounted for 85.78% of the variation in fish assemblage structure (and had eigenvalues >1.0, Table 3), with the first two components accounting for more than 80.27%. We found three groups of species, which were the same as in the CA.

From these analyses, three assemblages appeared: Shallow assemblage comprised Shelf Group I (comprising sets shallower than 250 m); Intermediate assemblage (Upper Continental Slope) Group II, comprising sets between 251 and 600 m; Deep assemblage (Medium and Lower Continental Slope) Group III, comprising sets deeper than 601 m. The three main groups: Shallow, Intermediate and Deep agree with the three different patterns found in the cumulative distribution.

American plaice, witch flounder and Atlantic cod formed the first assemblage (Group I, Shallow). The second assemblage (Group II, Shallow) comprised Acadian redfish, Arctic eelpout, thorny skate, longfin hake, deepwater redfish, spinytail skate and Northern wolffish. Atlantic wolffish, golden redfish, spotted wolffish were included in both, first and second assemblage. The third assemblage (Group III, Deep) comprised sixteen species: Marlin-spike, scaly dragonfish, Greenland halibut, sloane's viperfish, black dogfish, Snubnosed spiny eel, roughhead grenadier, roundnose grenadier, blue antimora, threadfin rockling, bean's sawtoothed eel, northern cutthroat eel, lanternfish, vahls's eelpout, Arctic skate and Demon catshark.

Table 4 shows the demersal species with most presence (as a percentage of the total biomass), as the percentage of abundance and of occurrence for each assemblage. Table 5 presents the number of species, the index of diversity, the number of stations, the total catch and the CPUE in the three depth zones. The highest value of diversity (H=2.01) is reached in the deeper assemblage.

In assemblage I, golden redfish is the most dominant species. Acadian redfish and cod had almost the same dominance (27, 65 % and 25, 65% respectively). American plaice, cod and witch flounder were dominant with an occurrence higher than 87%. The three species of redfish were the dominant species in assemblage II with a very high proportion of biomass in comparison with the proportion of other species in the same group and an occurrence bigger than 80 %. In group III, Greenland halibut, roughhead grenadier and blue antimora were the dominant species but those species together with roundnose grenadier, Northern cutthroat eel and marlin-spike had an occurrence higher than 90 %.

In general, the most dominant taxon was redfish. Redfish biomass was very high in the assemblages I and II, whereas the proportion of species was most homogeneous in the deep assemblages (III). For those reasons biodiversity index was higher in the deep group (Table 5).

Some species (like longfin hake, like marlin-spike and blue antimora and Greenland halibut) showed a well marked "bigger-deeper" distribution (Table 6). One species, *Glyptocephalus cynoglossus*, showed a significant negative correlation.

Discussion

The general results show similar general patterns to the previous analysis (Paz and Casas 1996; González-Troncoso *et al.*, 2006). Our analysis of EU Flemish Cap trawl survey data identified three main assemblages correlated with depth. The three groups obtained in the cluster analysis (Figure 5) can be associated with the shelf (Group I between 129 and 250 m), upper slope (Group II, between 251 and 600 m) and middle and lower slope (Group III, below a depth of 601 m). Paz and Casas (1996) and González-Troncoso *et al.* (2006) did same analysis with almost same group of species but a narrower depth range, and they also found a similar approach. Five new deep species, not present in the previous assemblages studies in Flemish Cap (Paz and Casas, 1996; González-Troncoso *et al.*, 2006), are selected due to the

larger deep range analysed: black dogfish, roundnose grenadier, lanterfish, Artic skate and demon catchark.

Fish fauna diversity in this study (155 taxa) represents only 64 % of the 240 taxa obtained between 2002 and 2011 from 38 to 1460 m in the South of the Grand Banks, Divisions 3NO of NAFO Regulatory Area (Nogueira *et al.*, 2013).

Biomass and abundance of main commercial species showed a shift since 1988 when the surveys started. Atlantic cod increased and reached historical levels and the fishery was reopened after 10-years of moratorium. In the South of the Grand Banks, Atlantic cod increased but did not reached historical levels (Nogueira *et al.*, 2013). Twenty years after the moratorium of American plaice, this species does not present signs of recovery. Same situation was found in divisions 3NO (Nogueira *et al.*, 2013) for this species.

Most of the studies on demersal fish assemblages have indicated that the main faunal changes occur along the depth gradient, so depth is the factor which most influenced the distribution of the species (Murua and De Cardenas, 2005; Bianchi, 1991; Moranta *et al.*, 1998; Labrapoulou and Papaconstantinou, 2004; Tomilieri and Levin, 2006). Changes in relation to depth were probably related to change in temperature and oxygen levels (Tomilieri and Levin, 2006). Physical characteristics of water masses, as well as bottom type, light intensity, pressure, etc., are mostly depth-dependent, and depth obviously reflects the combined effects of these factors (Bianchi, 1991).

We observed that the two main commercial species present again the bathymetric range found by Paz and Casas (1996) during the period 1989-2004. During the collapse, cod reduced and American plaice extend their depth range. González-Troncoso *et al.* (2006) found for cod a depth range of 126-343 m for years 1995-2002, when the species was collapsed. For years 2004-2013 we found a depth range of 129-652 and

for the period 1989-1994, the deep range was 126-631 m (Paz and Casas, 1996). An opposite situation was found for American plaice. For the period 1995-2002 the depth range was 126-716 m and we found a depth range of 129-479 m, similar of the period pre-collapse (1989-1995). We might be at a period of partial recovering.

The most important boundary was found at 600 m with a very low value of PS. This value is lowest than the one found by Paz and Casas (1996) at the same boundary, which means more zonation in our study. The zones established from cluster analysis coincide with the zones defined in the calculation of the Percentage of Similarity index. Same was found by Paz and Casas (1996), González-Troncoso *et al.* (2006) and Nogueira *et al.* (2013). If we compare the boundaries found by Paz and Casas (1996) and González-Troncoso *et al*. (2006), the shallow assemblage was reduced to 250 m probably because during this period the three main shallower species (Atlantic cod, American plaice and witch flounder) have been most abundant at shallower areas. On the other hand, the deepest assemblage extends it depth boundary to 600 m (same found by Paz and Casas, 1996). All analyses are agree with that species follow two main patterns: shallow or deep, even if we can observed one more (intermediate assemblage with some species superimpose). Composition of assemblages is consistent with assemblages found by Paz and Casas (1996) and González-Troncoso *et al.* (2006) but with some differences. The most important difference is for Greenland halibut, that is assigned to another group in this analysis. In this study, Greenland halibut is in the deepest assemblage with median depth of 800 m while Paz and Casas (1996) and González-Troncoso *et al.* (2006) found this species in the intermediate assemblage with median depth less than 500 m. During the period 1988-2002, Greenland halibut moved into shallower waters and became more abundant at depths of 256-549 m than 549-730 m. This range of expansion to shallower waters can be attributable to small fish (Hendrickson and Vázquez, 2005). At depths less than 730 m, few fish were larger of 60 cm (Alpoim *et al*., MS 2002). Greenland Halibut extended its range to shallower waters previously inhabit by Atlantic cod and American plaice when these species were collapsed (Hendrickson and Vázquez, 2005). Other differences is that two species, golden redfish and wolffish, were found only

in the assemblage I by González-Troncoso *et al.* (2006) while in our analysis they were found in groups I and II. Deepwater redfish in our analysis is a deeper species that was found only in the assemblage II. González-Troncoso *et al.* (2006) found this species superimpose in the assemblages I and II.

Both abundance and biomass declined with depth, however diversity is higher at bigger depths. This fact has an important effect on fish community structure and eventually on the traditional fisheries (Gordon *et al.*, 1994) The most commercially important species tend to be present in low diversity communities where they are a significant proportion of the total biomass (Headrich, 1994). In line with this assertion, the Shelf and Upper Continental Slope presented the smallest diversity and were the regions where the traditional commercial species exploited in the area live, such as Atlantic cod and redfish. Same results were found in Flemish Cap by Paz and Casas (1996) and González-Troncoso *et al.* (2006), and in the South of the Grand Banks by Nogueira *et al.* (2013). Note that values of diversity are more similar to those found by Paz and Casas (1996) for the period 1989-1995 than those found by González-Troncoso *et al.* (2006) for the period 1996-2002.

We observed changes in dominant species composition in each assemblage over time. Dominance of Atlantic cod increases if we compare it with the period 2002-2006 (González-Troncoso *et al.*, 2006) but does not reach the levels of dominance found between 1992 and 1994. When comparing the assemblage II with Paz and Casas (1996) and González-Troncoso *et al.* (2006), dominance of Acadian redfish and golden redfish increases while deepwater redfish decreases. Genus redfish continues to be the most dominant in assemblages I and II. Decreasing on biomass of traditional target species for commercial fishing area, such as Atlantic cod and American plaice, can be a cause of changes in the composition of assemblages (Hutchings, 2000; González-Troncoso *et al.*, 2006; Nogueira *et al.*, 2013). The same was observed in the South of the Grand Banks for the period 2002-2011 by Nogueira *et al.* (2013). A similar pattern presented between Southern Grand Banks and Flemish Cap in the evolution of these fish

assemblages indicates that changes in fish populations in the Northwest Atlantic have been produced on a large scale, affecting Large Marine Ecosystem, and not limited to specific areas (Nogueira *et al.*, 2013).

Dominance in the deep assemblage is not comparable with Paz and Casas (1996) nor González-Troncoso *et al.* (2006) because this assemblage has a much larger depth range in our analysis and includes five more deep species. Nevertheless, composition is very similar with the fifth assemblage described by Nogueira *et al.* (2013) in the South of the Grand Banks.

Witch flounder showed a significant negative correlation with depth. Paz and Casas (1996) and Nogueira *et al.* (2013) found same correlation for this species in Flemish Cap and South of the Grand Banks respectively. Burnett *et al.* (1992) found significant differences in distribution according to depth for juveniles and adults of this species in the Gulf of Maine-Georges Bank Region and, while adults maintained a mean depth constant throughout the year, juveniles were found at shallower depths than adults in winter and spring, and at greater depths in summer and fall. This is attributed to differences in prey distribution associated with differences in the diet (Bunnet *et al.*, 1992).

Conclusions

- Despite shift in abundance and biomass of the main commercial and non-commercial fishes, we observed persistence in the species composition and range of assemblages.
- Redfish replaced Atlantic cod and becoming the dominant species in shallow assemblage.
- Zonation at boundary of 600 m has increased and species tend to be shallower or deeper.
- Assemblages composition and dominance of species is now more like the pre-collapse period than to the collapse period.
- Higher diversity was observed in deeper depths and diversity values are more similar to those of pre-collapase period than to the collapse period.

- Assemblage composition persistence and changes in the main dominant species were similar to the changes in near ecosystems such as the South of the Grand Banks.
- The variation pattern in the fish assemblages in the Southern Grand Banks, similar to other Northwest areas, indicates that changes in fish populations in the Northwest Atlantic have appeared on a large scale and have not been limited to specific areas.

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Table 1.- Number of hauls, depth covered, dates and number of species by year. R/V *Vizconde de Eza* has been used in the studied period.

Year	Vali hauls	Depth range (m)	Dates
2004	179	138-1349	June 25 - August 2
2005	176	132-1424	July 1st -August 2
2006	179	139-1450	July 1st - July 26
2007	174	143-1435	June 23 - July 19
2008	167	130-1460	June 23 - July 19
2009	178	135-1440	June 23 - July 20
2010	153	132-1439	June 23 - July 19
2011	138	138-1430	June 29 - August 9
2012	174	136-1440	June 26 - July 24
2013	181	129-1457	June 24 -July 28
2004-2013	1699	129-1460	

Table 2.- Vertical ranges and catch data for the chosen fish species taken by bottom trawls in the EU Flemish Cap surveys (2004-2013) including all valid hauls.

Main Fish Species	Common name	FAO CODE	Depth Range	Weight (kg)	No. Of Stations	Occurence (%)
Sebastes fasciatus	Acadian redfish	REN	138-992	212154.77	990	58.27
Sebastes marinus	Golden redfish	REG	130-631	160232.13	820	48.26
Sebastes mentella	Deepwater redfish	REB	138-1218	124194.53	825	48.56
Gadus morhua	Atlantic cod	COD	129-652	68114.50	726	42.73
Reinhardtius hippoglossoides	Greenland halibut	GHL	138-1459	34383.71	1216	71.57
Antimora rostrata	Blue antimora	ANT	171-1459	10978.37	734	43.20
Macrourus berglax	Roughhead grenadier	RHG	243-1459	10947.47	886	52.15
Centroscyllium fabricii	Black dofish	CFB	415-1457	7245.51	451	26.55
Coryphaenoides rupestris	Roundnose grenadier	RNG	171-1460	7063.39	654	38.49
Synaphobranchus kaupii	Northern cutthroat eel	SSK	416-1459	4807.60	665	39.14
Anarhichas denticulatus	Northern wolfish	CAB	152-1350	3889.90	632	37.20
Hippoglossoides platessoides	American plaice	PLA	129-479	3704.29	585	34.43
Anarhichas minor	Spotted wolfish	CAS	132-1091	3659.85	503	29.61
Amblyraja radiata	Thorny skate	RJR	132-1180	3054.65	679	39.96
Anarhichas lupus	Atlantic wolffish	CAA	130-1356	2600.78	645	37.96
Nezumia bairdii	Marlin-spike	NZB	227-1439	2262.05	1216	71.57
Glyptocephalus cynoglossus	Witch flounder	WIT	129-1164	1983.73	699	41.14
Apristurus sp.	Demon catshark	API	988-1459	1889.83	160	9.42
Gaidropsarus ensis	Threadfin rockling	GDE	194-1457	1305.68	678	39.91
Bathyraja spinicauda	Spinytail skate	RJQ	181-1435	1273.14	169	9.95
Lycodes reticulatus	Arctic eelpout	LCT	187-1311	1172.22	390	22.95
Notacanthus chemitzii	Snubnosed spiny eel	NNN	289-1459	1014.92	475	27.96
Amblyraja hyperborea	Arctic skate	RJG	569-1459	800.84	129	7.59
Phycis chesteri	Longfin hake	GPE	194-956	602.35	558	32.84
Serrivomer beanii	Bean's sawtoothed eel	ASB	314-1459	260.72	616	36.26
Lampanyctus sp.	Lanternfish	SP1	240-1460	171.81	533	31.37
Chauliodus sloani	Sloane's viperfish	CDN	252-1460	155.32	725	42.67
Lycodes vahlii	Vahl's eelpout	SP2	275-1476	126.59	213	12.54
Stomias boa	Scaly dragonfish	SBB	142-1459	105.72	801	47.15

[1] non-FAO codes

Table 3.- Eigenvalues from the Principal Component Analysis performed on root-root transformed data.

Value	Eigenvalues	% total variance	Cumulative eigenvalue	Cumulative %
1	18.37	63.35	18.37	63.35
2	4.91	16.92	23.28	80.27
3	1.60	5.51	24.88	85.78

Table 4.- Most abundant fish species at the three depth zones considered. Values are percentages of total biomass and occurrence.

Dominant species	**Biomass (%)**	**Number(%)**	**Ocurrence(%)**
Depths ≤ 250 m (I)			
Sebastes marinus	41.20	39.46	86.75
Sebastes fasciatus	27.63	51.22	58.36
Gadus morhua	25.65	7.64	92.74
Hippoglossoides platessoides	2.02	0.33	92.43
Glyptocephalus cynoglosssus	1.07	0.21	87.70
Anarhichas lupus	0.66	0.15	74.45
Amblyraja radia	0.48	0.03	58.04
TOTAL	98.71	99.04	
Depths between 251 and 600 m (II)			
Sebastes fasciatus	38.60	46.32	99.26
Sebastes mentella	27.29	32.54	90.25
Sebastes marinus	22.97	17.86	80.06
Gadus morhua	6.48	1.44	63.22
Reinhardtius hippoglossides	1.50	0.36	70.90
Anarhichas minor	0.69	0.06	60.12
Amblyraja radiata	0.49	0.05	65.58
TOTAL	98.04	98.64	
Depths ≥ 600 m (III)			
Antimora rostrata	35.18	12.12	95.46
Reinhardtius hippoglossides	14.00	20.64	99.29
Macrourus berglax	12.86	7.41	98.87
Centroscyllium fabricii	9.27	2.44	63.55
Coryphaenoides rupestris	9.05	18.95	90.78
Synaphobranchus kaupii	6.16	13.18	91.35
Apristurus sp	2.42	0.44	22.70
Nezumia bairdii	2.33	11.75	94.89
TOTAL	91.28	86.93	

Table 5.- Community parameters and catch rates for fish assemblages by depth strata on Flemish Cap in the period 2004-2013.

	Depth strata (m)		
	129- 250	251-601	600-1460
Number of species	21	28	29
Diversity, H	1.33	1.48	2.1
Number of stations	317	677	705
Catch (kg)	154637	437534	77983
CPUE (kg / 30 min tow)	488	646	111

Table 6.- Parameters for the regression of mean weight per individual by species versus depth where the fit was significant.

			Parameteres of Equation y=ax+b	
Species	No. Of Cases	Correlation coefficient	a	b
Gadus morhua	726	0.229	0.008	-0.447
Amblyraja radiata	750	0.0036	0.003	2.5171
Glyptocephalus cynoglossus	699	0.2662	-0.007	0.6476
Sebastes marinus	819	0.1402	0.001	0.0237
Sebastes mentella	822	0.5046	0.0007	0.0674
Coryphaenoides rupestris	653	0.2917	0.003	-0.0913
Antimora rostrata	733	0.5099	0.0004	-0.1145
Nezumia	1214	0.5335	0.00005	0.0128
Phycis chesteri	558	0.6449	0.007	0.132
Reinhardtius hippoglossoides	1216	0.3971	0.0007	0.4381

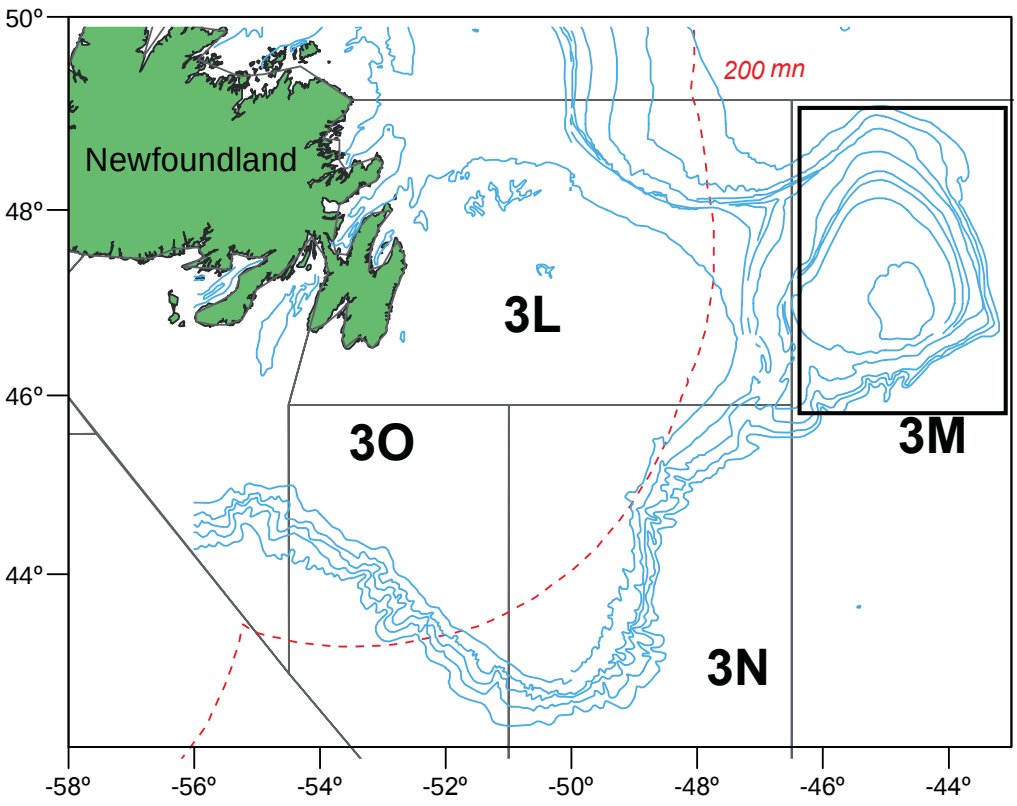

Figure 1.- Chart of the NAFO Divisions 3LMNO. EU bottom trawl area in NAFO Regulatory Area Divisions 3M is marked by the square.

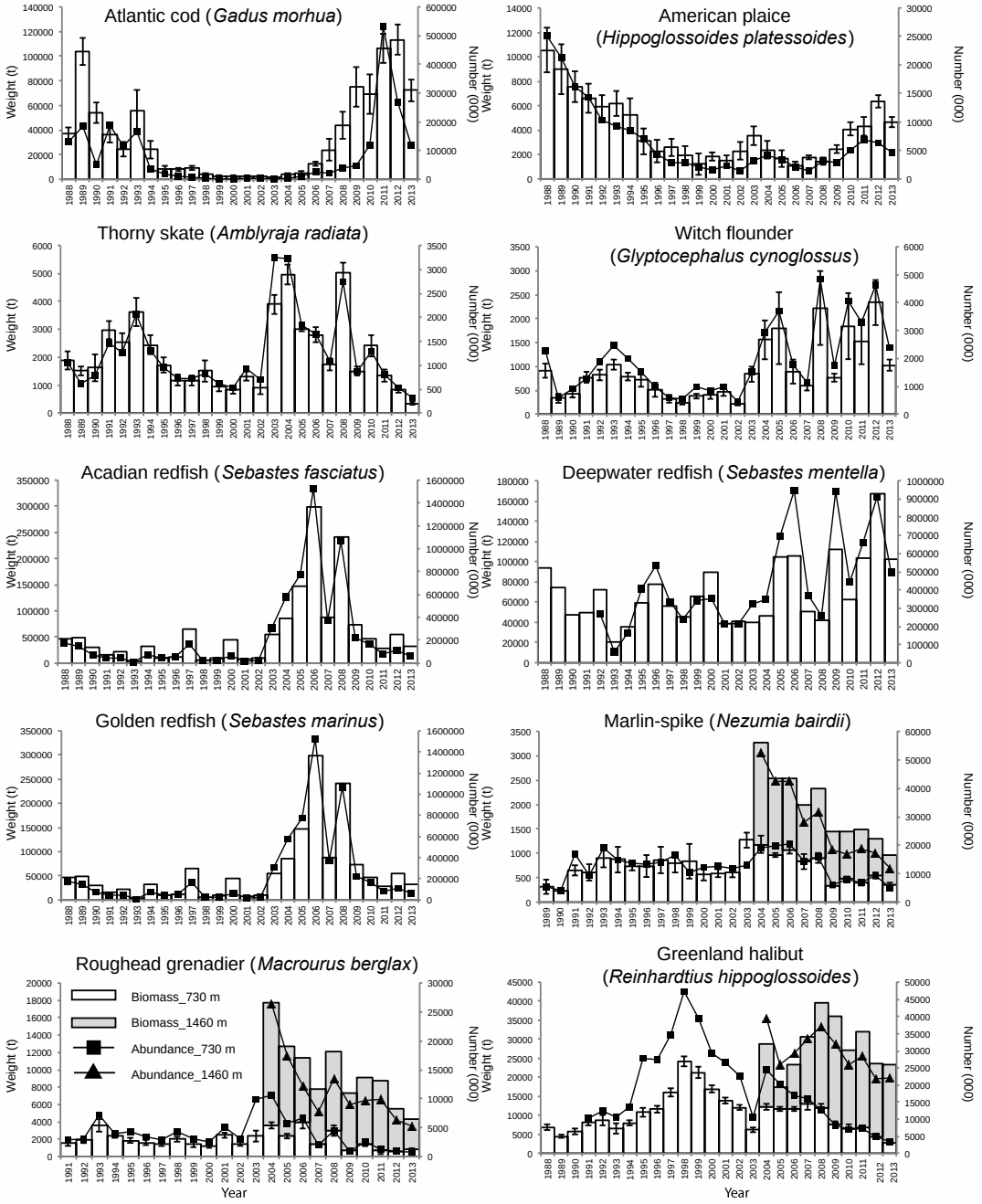

Figure 2.- Abundance and biomass estimates for the main species from EU Flemish Cap bottom trawl survey (2004-2013).

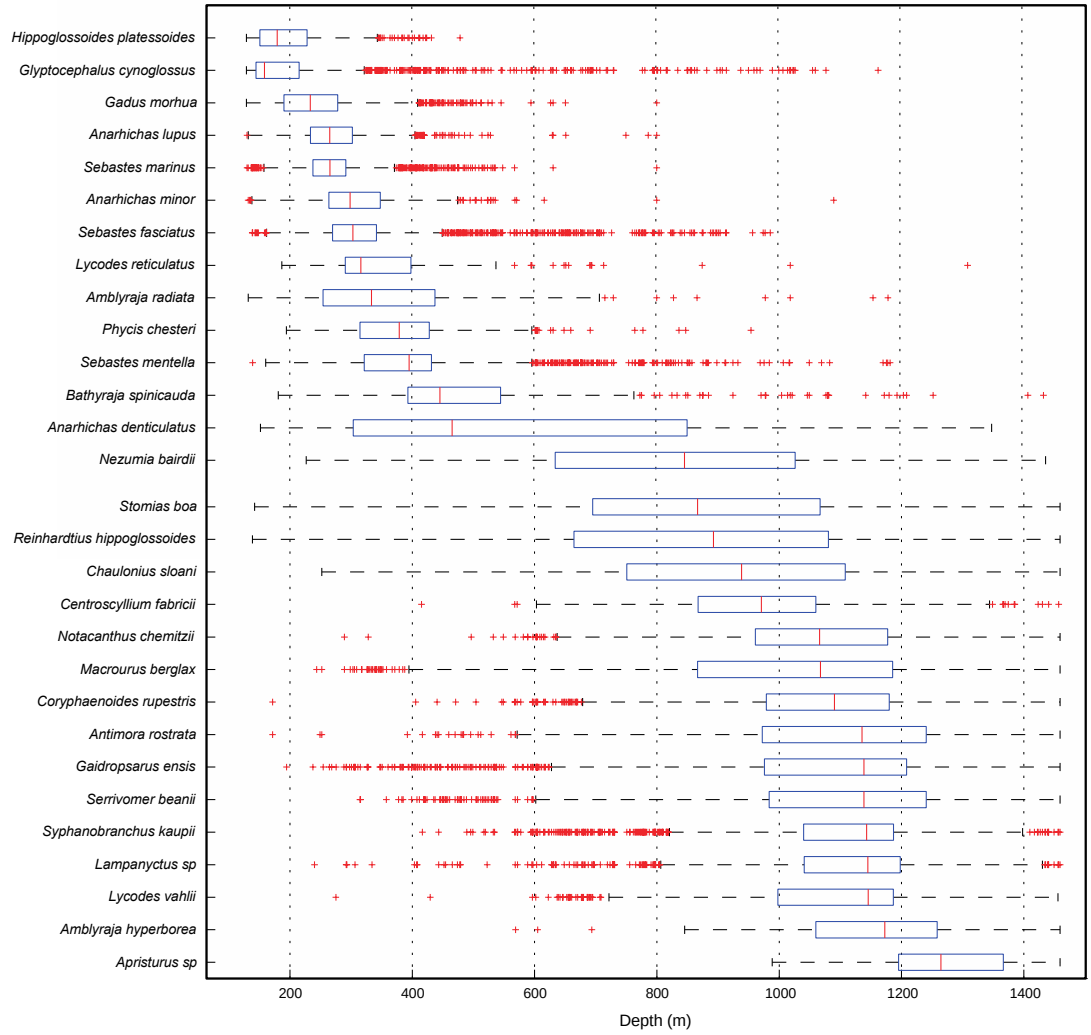

Figure 3.- Box-Plots of depth distribution for the most abundant species in the EU Flemish Cap bottom trawl survey (2004-2013). Median and quartiles are represented. Species are ordered by increasing median depth catches value so we can observe an increasing gradient of depth for each one.

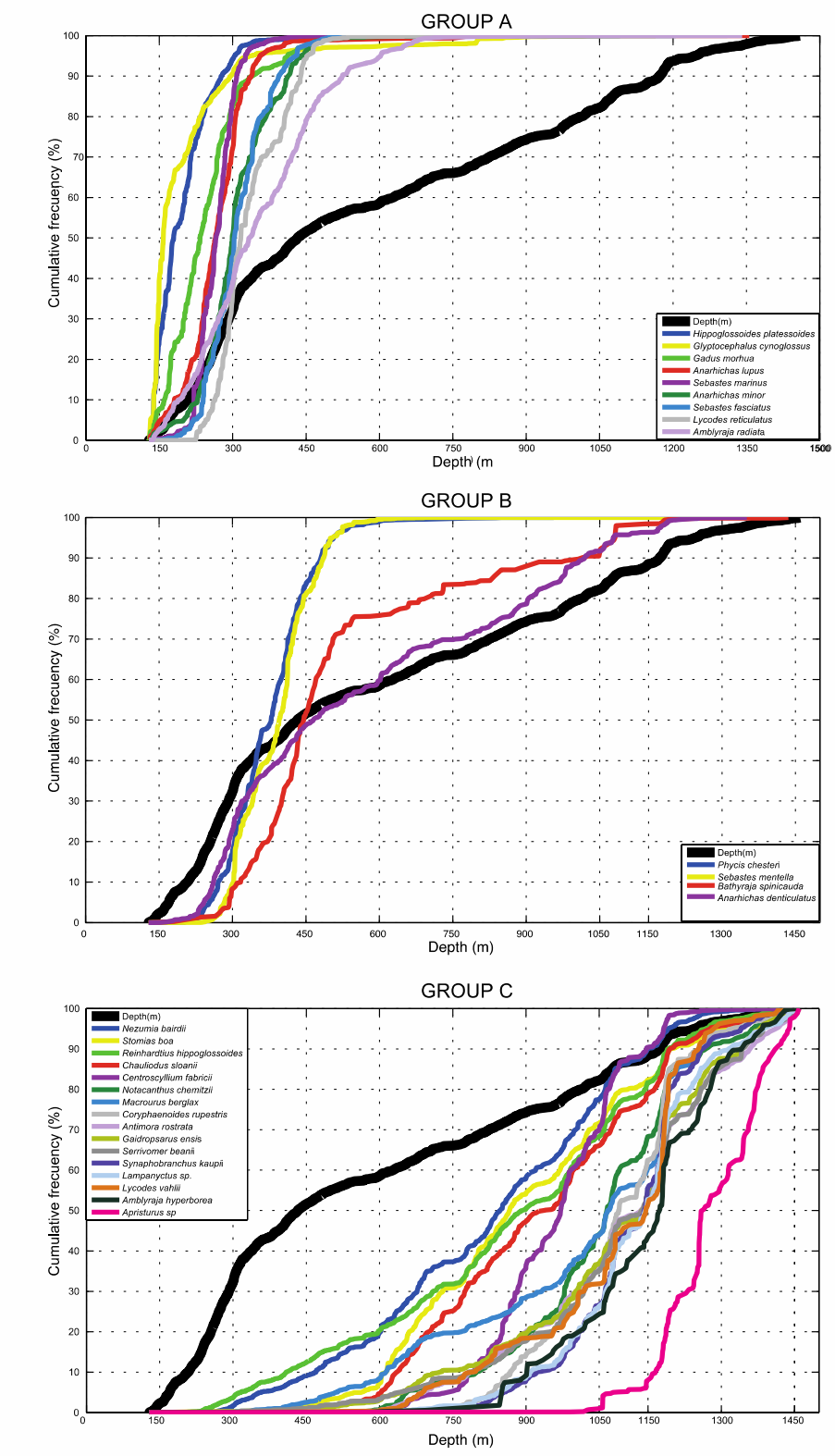

Figure 4.- Cumulative frequency distribution of habitat variable (bottom depth) and catch data from the EU Flemish Cap bottom trawl survey (2004-2013).

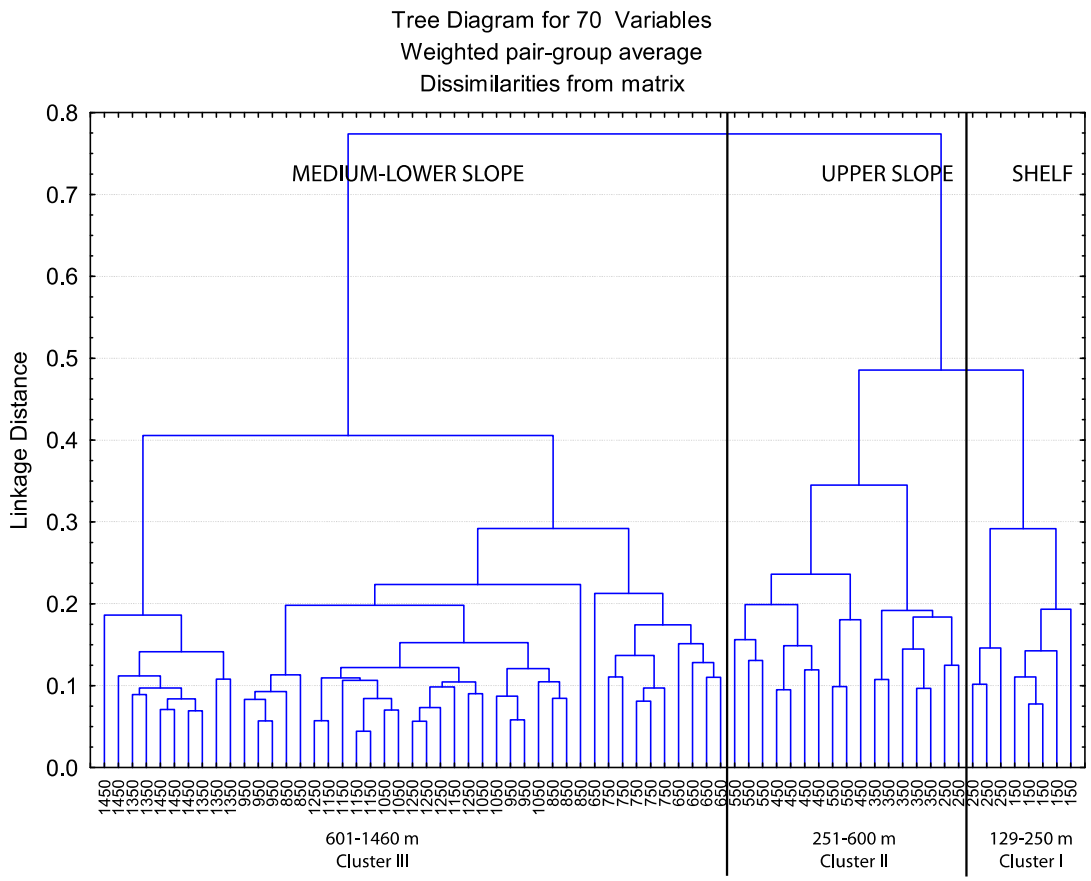

Figure 5.- Dendogram showing the classification of 1699 sets grouped in 10 depth class of 100 m by two years (2004-05, 2006-07, 2008-09, 2010-11, 2012-2013) based on mean abundance of fish fauna species composition by depth class. Catch was root-root transformed before comparing stations using the Bray-Curtis measure, and the dendogram formed by group-average sorting. Three clusters are distinguished.

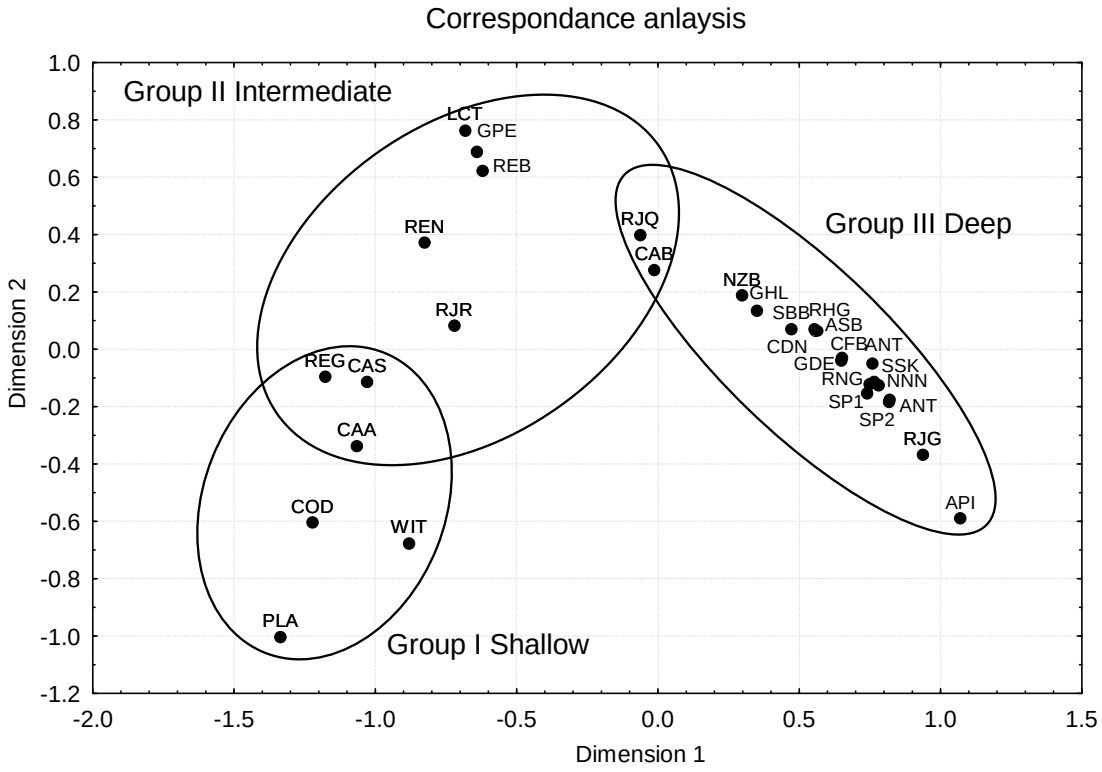

Figure 6.- Data on species assemblages and distribution from the EU Flemish Cap bottom trawl survey (2004-2013), all years combined. Correspondence Analysis ordination plot of axes I and II relating abundance variations to the depth range: 129-1460 m. Hauls number: 1699.

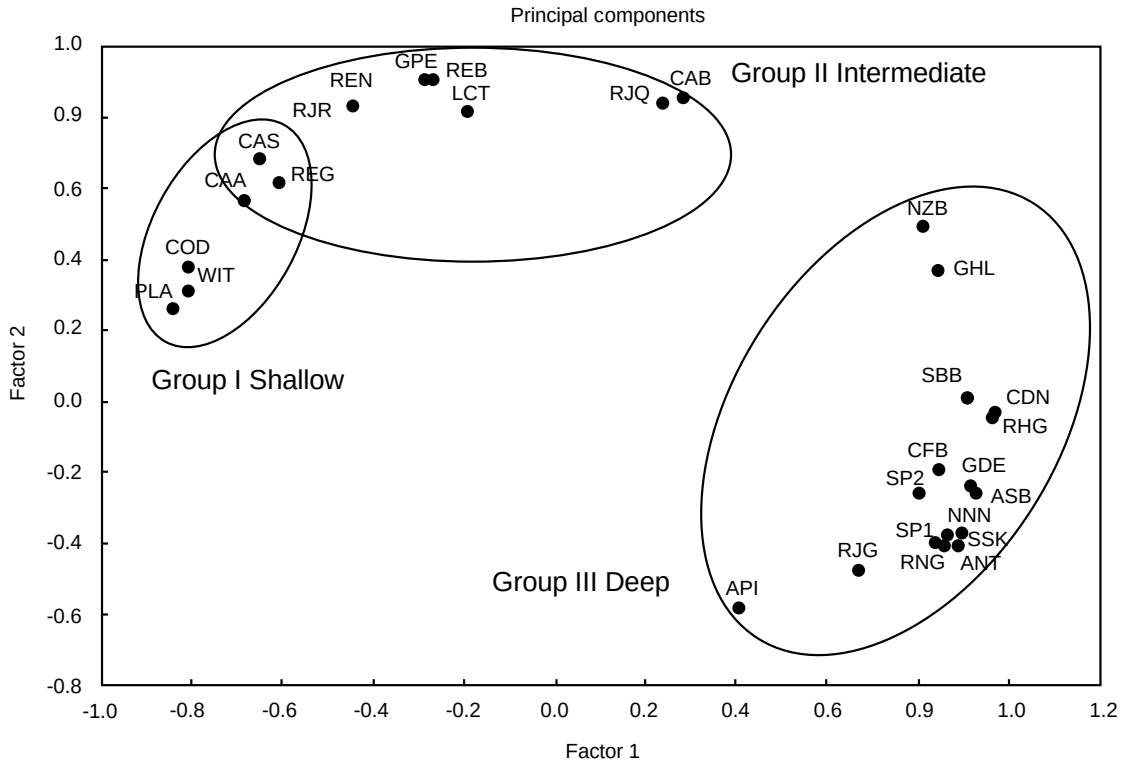

Figure 7.- Data on species assemblages and distribution from the EU Flemish Cap bottom trawl survey (2004-2013), all years combined. Principal Components Analysis ordination plot of axes I and II relating abundance variations to the depth range: 129-1460m. Hauls number: 1699.